

Community tools for model initialization, spin-up, and evaluation

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Building a Next-Generation Community Ice Sheet Model, LANL

Outline

Basic tools: NetCDF etc.

Initialization and spin-up of CISM

Evaluation of CISM results

Conclusion

Introduction

- Bill L. has suggested participants should “stand on a soapbox and tell us what a community ice sheet model should look like”
- should Bill be more careful what he asks for?

My soapbox

- what should CISM look like to a glaciologist or ice sheet modeling *user*?
- focus on:
 - * input and output file formats and tools
 - * publicly available data sets
 - * initializing/spinning-up a CISM model run
 - * evaluating CISM model outputs
- not focussed on: model internals, coupling to a climate model
- the start of an ongoing conversation, I hope

Conflict-of-interest disclaimer

- I am associated with the development of the Parallel Ice Sheet Model (PISM)
- it would be silly not to plug it: www.pism-docs.org
- PISM is
 - * open source, but
 - * not “community” controlled; that’s o.k.
- my hope for PISM: follow CISM to be another ISM that can talk to CCSM’s coupler and be used as an alternate ice sheet component
- my talk reflects my experience getting PISM going as a Greenland and Antarctic ice sheet model

NetCDF file format

- NetCDF = network Common Data Form
- already the standard for CCSM, GLIMMER, PISM
- allows metadata (e.g. units, projection, file history, ...)
- binary storage with fast read/write; parallel in NetCDF4 (uses HDF5)
- few restrictions on what you put in a NetCDF file

Example of text form (.cd1):

```
netcdf eis_green20 {  
  dimensions:  
    t = UNLIMITED ; // (1 currently)  
    x = 141 ;  
    ...  
  variables:  
    double t(t) ;  
      t:units = "seconds since 2007-01-01 00:00:00" ;  
    ...  
    float thk(t, x, y) ;  
      thk:standard_name = "land_ice_thickness" ;  
    ...  
  // global attributes:  
    :history = "Thu Aug 14 .... ./eis_green.py\n",  
  data:  
    ...  
    thk = 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, ...  
}
```

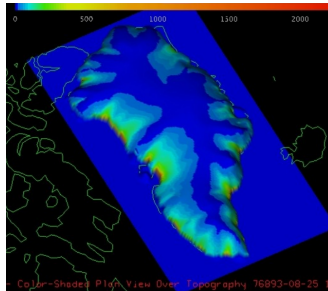
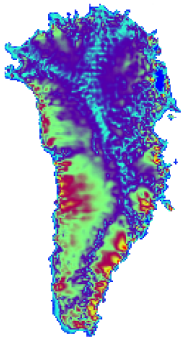
Climate and Forecast (CF) Metadata Convention

- <http://cf-pcmdi.llnl.gov/documents/cf-conventions/1.3>
- specifies how climate-related NetCDF files should look; “facilitates building applications with powerful extraction, regridding, and display capabilities”
- gives a standard name list for modeling variables
- in 2004 GLIMMER author Hagdorn submitted standard names for ice sheets to CF (below)
- extend/revise these examples?

STANDARD NAME	UNITS
...	
land_ice_basal_melt_rate	m s ⁻¹
land_ice_basal_x_velocity	m s ⁻¹
...	
land_ice_temperature	K
land_ice_thickness	m
...	

NetCDF visualization

- fast, basic viewing with `ncview` (BELOW LEFT);
http://meteora.ucsd.edu/~pierce/ncview_home_page.html
- better 3D, projected, etc. viewing with `IDV` (BELOW RIGHT);
<https://www.unidata.ucar.edu/software/idv/>
- other viewers and tools available for NetCDF but some are too meteorology-centric



NCO = NetCDF operators

- powerful command line manipulation of NetCDF files
- <http://nco.sourceforge.net/>

GOAL

compare thickness from
two files; put in new file

compute flux from
thickness and vertically-
averaged speed

change units attribute

EXAMPLE NCO COMMAND

```
ncdiff -v thk green_y1.nc green_y2.nc thkdiff12.nc
```

```
ncap -O -s 'flux=thk*cbar' green_y1.nc green_y1.nc
```

```
ncatted -O -a units,precip,m,c,"m w. eqv. a-1" foo.nc
```

Scripting to prepare data

- basic process for getting data into an ISM:
 1. get data in text format by email (or `http:...` if lucky)
 2. figure out the idiosyncratic scheme for missing values, units, grid, etc.
 3. write script in Python, IDL, Matlab, Fortran, etc. to convert data to ISM-readable form (e.g. NetCDF)
 4. goto 1. (≥ 10 email iterations required to resolve issues)
- this tends to be ugly and require both personal connections and lots of modeler spin-up ... ; can we make it easier?

Cont.

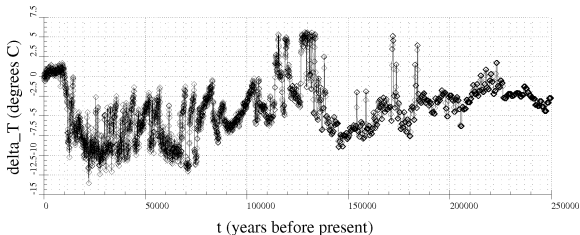
- PISM distribution already includes a bunch of Python scripts which turn various public data (e.g. EISMINT) in various formats into NetCDF
- GLIMMER too?
- proposal: these scripts *and their NetCDF outputs* could start CISM user/data website?
- maintainer needed?
- ISM community pressure to standardize format including metadata at NSIDC? BEDMAP? Antarctic Digital Database?

Thank goodness for ...

- EISMINT has posted lots of public data suitable for ice sheet modeling (<http://homepages.vub.ac.be/~phuybrec/eismint.html>):
 - * Greenland ice sheet
 - * Antarctica ice sheet
 - * Ross ice shelf
- also has GRIP, Vostok, SPECMAP paleoclimate time series
- observations more than 15 years old [*modeler sad*]
- low resolution only [*more sadness*]
- future reality-based intercomparisons will post data? in standard format(s) with metadata?

Time series and paleoclimate

- GRIP temperature record shown below
- how to use this and other time series to produce high quality model of **current** ice sheets?
- (needed because observations of current ice sheets do not give initial conditions for the PDEs of ice flow)
- prominently missing:
 - * temperature within the ice
 - * till strength and
 - * saturation (pore water pressure) at base of ice
 - * anisotropy, impurities, etc. in ice



Initialization versus spin-up: The basic choice

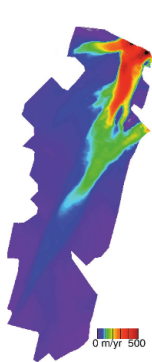
- Two options:
 1. use inverse modeling of rich and spatially-distributed (but still incomplete!) observations of current ice sheet state, and lots of inverse modeling, to directly reconstruct current ice sheet state
 2. use low-dimensional time series data from physical surrogates (e.g. $\delta^{18}O$ record from ice core) for paleoclimate record, and hope that a long model run produces close to current ice sheet
- Only 2 used for whole ice sheet modeling, so far,
- because 1 is in infancy.
- A false dichotomy: we'll do both. How to best use
current/spatial/hi-res
and
paleo/point-measurement/low-dimensional
data sets?

Practical idea: lightweight paleo-CLM

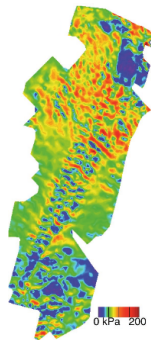
- when time series like GRIP, Vostok records are used they drive
 - * a surface energy balance model (i.e. how the temperature offset becomes the ice surface temperature boundary condition, perhaps as function of elevation and latitude),
 - * a surface mass balance model (e.g. add a spatial distribution for snow rate and a PDD), and
- this tends to be special code within an ISM
- code which produces same as what CLM (Community Land Model, as modified by Bill L.) produces for coupled runs with GLIMMER [I think]
- how about a light-weight program which reads paleo records—time series—and then pretends to be CLM (or the CCSM coupler), producing surface mass and energy balance?
- thus paleo CISM runs just like climate scenario CISM runs

Surface velocity observations for inverse modeling

- ideally: use observed surface velocity to initialize ISM
- “inverse modeling”: use PDE to determine most likely boundary condition, given partial solution
- done for individual ice streams and glaciers (e.g. →)
- how to convert basal shear stress to till strength property?



observed velocity of
NE Greenland ice
stream

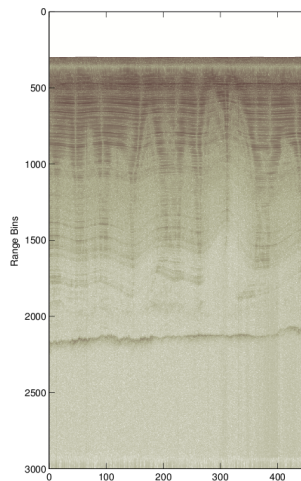


estimated basal shear
stress

(Joughin et al 2001 JGR)

Other data for initialization

- observed geothermal flux
- surface elevation rate (MAMM? IceSat?); allows removal of steady state assumption in spin-up?
- isochrones (right →) are integrated ice advection history; how to use?
- bed reflectivity to constrain model estimate of saturated till?
- observed bed uplift rates are time-integrated ice load history; use to constrain paleoglacial runs and spin-up?



CRESIS (U. Kansas) radio
echogram, Greenland 5/13/03
<http://tornado.rsl.ku.edu/2003pdf.htm>

I'll try to watch my language . . .

- *verification* = are numerical results close to predictions of the approximated continuum model?
- *validation* = are numerical results close to high quality, relatively-complete observations of nature?
- *evaluation* = my generic term for comparing observations and model results

Verification easy when it is possible

- exact solutions exist (upper right)
- only for partial models
- used this way:
 1. read initial cond from exact soln procedure (lower right)
 2. during run, only read source terms like accum from exact soln
 3. at end of run, compare model result to exact soln
- easy to add these to CISM; I'm volunteering

Some exact solutions in PISM:

Test	Continuum model tested
...	
D	isothermal SIA, time-varying accum
...	
F	thermomechanically-coupled SIA
...	
J	shelf velocity computation
K	pure conduction in ice and bedrock
...	

Fortran signature for an exact solution:

```
subroutine testF(r,z,H,T,U,w,Sig,M,Sigc)
  real(kind), intent(in) :: r, z
  real(kind), intent(out) :: H, T, U, w,
                               Sig, M, Sigc
  ...
end subroutine testF
```

Validation

- “ice sheet model validation” presumably means comparing model to very well studied small ice cap or a part of an ice sheet
- validation means actually reporting the size of the difference
- examples exist: EISMINT-Ross, glacier examples
- parts of upcoming “St. Petersburg” intercomparison round (PIG, ice streams, Jakobshavn) might be validation?
- “competitive validation”? ISMs predict the result of *planned* observations

Validation is very hard, compared to other fluid cases

- validate by lab experiments with a shear-thinning fluid like . . . blood?
(Jed Brown suggestion)
- collaborate with material science folks to build full-scale, time-dependent validation for CISM?
- with temperature-dependence?
sliding? grounding line?

excerpt from Gijzen et al. 1999, *The influence of the non-Newtonian properties of blood on the flow in large arteries . . .*, J. Biomechanics:

The shear thinning was accounted for by employing the Carreau–Yasuda model (Bird et al., 1987):

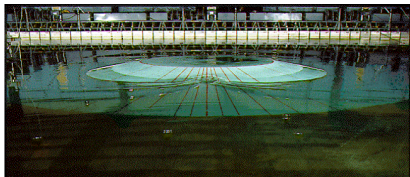
$$\frac{\eta - \eta_{\infty}}{\eta_0 - \eta_{\infty}} = [1 + (\dot{\gamma})^a]^{(n-1)/a} . \quad (5)$$

For $\dot{\gamma}$, a scalar measure of the rate of deformation tensor was used (Macosko 1994):

$$D = \frac{1}{2} [\nabla \mathbf{v} + (\nabla \mathbf{v})^T] \quad (6)$$

...

$$n = 0.392,$$



wavetank for simulating tsunami runup on conical island

Less formal evaluation of CISM outputs

- glaciologists probably skeptical of my “use rich data to initialize by inverse modeling” ... it raises more questions than it answers
- same data should (at least) be compared to model outputs
 - * surface velocities (SAR interferometry) ↔ model velocity
 - * surface elevation rate (SAR interferometry? laser altimetry?) ↔ model surface kinematical eqn
 - * isochrones ↔ advection model
 - * bed reflectivity ↔ model of till saturation
 - * observed bed uplift rates ↔ earth deformation model
 - * ice drilling measurements (temperature vs depth) ↔ model temperature
- how to evaluate model result for spatial distribution of sliding?

“Soapbox” conclusion . . .

- CISM can help modelers by making **community-based** choices of **standards**, like:
 - * NetCDF4, CF 1.3, added standard names to CF
 - * standardized/documented interface to CCSM coupler, and paleoclimate interface
- **scientific focus on initialization and spin-up needed!**
- how to use rich current-time data sets instead of low-dimensional paleo-data?
- community ISM needs **public data sources**, in portable format with metadata
- vital issue for CISM: **trustable results**, with understood limitations
- so CISM needs built-in or easily-available verification and validation

... but discussion just started

- blatant advertisement for breakout session:

Initialization, verification, and validation

Jemez Room, 3:00 pm today